

PENDING CLAIMS

1. (Issued Patent) An apparatus for coding, storing or transmitting, and decoding $M \times M$ sized blocks of digitally represented images, where M is an even number, comprising
 - a. a forward transform comprising
 - i. a base transform having M channels numbered 0 through $M-1$, half of said channel numbers being odd and half being even;
 - ii. an equal normalization factor in each of the M channels selected to be dyadic-rational;
 - iii. a full-scale butterfly implemented as a series of lifting steps with a first set of dyadic rational coefficients;
 - iv. $M/2$ delay lines in the odd numbered channels;
 - v. a full-scale butterfly implemented as a series of lifting steps with said first set of dyadic rational coefficients; and
 - vi. a series of lifting steps in the odd numbered channels with a second specifically selected set of dyadic-rational coefficients;
 - b. means for transmission or storage of the transform output coefficients; and
 - c. an inverse transform comprising
 - i. M channels numbered 0 through $M-1$, half of said channel numbers being odd and half being even;
 - ii. a series of inverse lifting steps in the odd numbered channels with said second set of specifically selected dyadic-rational coefficients;

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- iii. a full-scale butterfly implemented as a series of lifting steps with said first set of specifically selected dyadic-rational coefficients;
 - iv. $M/2$ delay lines in the even numbered channels;
 - v. a full-scale butterfly implemented as a series of lifting steps with said first set of specifically selected dyadic-rational coefficients;
 - vi. an equal denormalization factor in each of the M channels specifically selected to be dyadic-rational; and
 - vii. a base inverse transform having M channels numbered 0 through $M-1$.
2. (Issued Patent) The apparatus of Claim 1 in which the normalizing factor takes the value $25/16$ and simultaneously the denormalizing factor takes the value $16/25$.
 3. (Issued Patent) The apparatus of Claim 1 in which the normalizing factor takes the value $5/4$ and simultaneously the denormalizing factor takes the value $4/5$.
 4. (Issued Patent) The apparatus of Claim 1 in which the first set of dyadic rational coefficients are all equal to 1.
 5. (Issued Patent) The apparatus of Claim 1 in which the second set of dyadic rational coefficients are all equal to $1/2$.
 6. (Issued Patent) The apparatus of Claim 1 in which the base transform is any $M \times M$ invertible matrix of the form of a linear phase filter and the inverse base transform is the inverse of said $M \times M$ invertible matrix.
 7. (Issued Patent) The apparatus of Claim 1 in which the base transform is the forward $M \times M$ discrete cosine transform and the inverse base transform is the inverse $M \times M$ discrete cosine transform.

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8. (Issued Patent) An apparatus for coding, compressing, storing or transmitting, and decoding a block of $M \times M$ intensities from a digital image selected by an $M \times M$ window moving recursively over the image, comprising:
- a. an $M \times M$ block transform comprising:
 - i. an initial stage
 - ii. a normalizing factor in each channel
 - b. a cascade comprising a plurality of dyadic rational lifting transforms, each of said plurality of dyadic rational lifting transforms comprising
 - i. a first bank of pairs of butterfly lifting steps with unitary coefficients between adjacent lines of said transform;
 - ii. a bank of delay lines in a first group of $M/2$ alternating lines;
 - iii. a second bank of butterfly lifting steps with unitary coefficients, and
 - iv. a bank of pairs of butterfly lifting steps with coefficients of $1/2$ between $M/2 - 1$ pairs of said $M/2$ alternating lines;
 - c. means for transmission or storage of the output coefficients of said $M \times M$ block transform; and
 - d. an inverse transform comprising
 - i. a cascade comprising a plurality of dyadic rational lifting transforms, each of said plurality of dyadic rational lifting transforms comprising

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- a) a bank of pairs of butterfly lifting steps with coefficients of $1/2$ between said $M/2 - 1$ pairs of said $M/2$ alternating lines;
 - b) a first bank of pairs of butterfly lifting steps with unitary coefficients between adjacent lines of said transform;
 - c) a bank of delay lines in a second group of $M/2$ alternating lines; and
 - d) a second bank of pairs of butterfly lifting steps with unitary coefficients between adjacent lines of said transform;
 - ii. a de-scaling bank; and
 - iii. an inverse initial stage.
9. (Issued Patent) A method of coding, storing or transmitting, and decoding $M \times M$ sized blocks of digitally represented images, where M is a power of 2, comprising
- a. transmitting the original picture signals to a coder, which effects the steps of
 - i. converting the signals with a base transform having M channels numbered 0 through $M-1$, half of said channel numbers being odd and half being even;
 - ii. normalizing the output of the preceding step with a dyadic rational normalization factor in each of said M channels;
 - iii. processing the output of the preceding step through two lifting steps with a first set of identical dyadic rational coefficients connecting each pair of adjacent numbered channels in a butterfly configuration;
 - iv. transmitting the resulting coefficients through $M/2$ delay lines in the odd numbered channels;

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- v. processing the output of the preceding step through two inverse lifting steps with the first set of dyadic rational coefficients connecting each pair of adjacent numbered channels in a butterfly configuration; and
 - vi. applying two lifting steps with a second set of identical dyadic rational coefficients connecting each pair of adjacent odd numbered channels to the output of the preceding step;
- b. transmitting or storing the transform output coefficients;
- c. receiving the transform output coefficients in a decoder; and
- d. processing the output coefficients in a decoder, comprising the steps of
- i. receiving the coefficients in M channels numbered 0 through M-1, half of said channel numbers being odd and half being even;
 - ii. applying two inverse lifting steps with dyadic rational coefficients connecting each pair of adjacent odd numbered channels;
 - iii. applying two lifting steps with dyadic rational coefficients connecting each pair of adjacent numbered channels in a butterfly configuration;
 - iv. transmitting the result of the preceding step through M/2 delay lines in the even numbered channels;
 - v. applying two inverse lifting steps with dyadic rational coefficients connecting each pair of adjacent numbered channels in a butterfly configuration;
 - vi. denormalizing the result of the preceding step with a dyadic rational inverse normalization factor in each of said M channels; and

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- vii. processing the result of the preceding step through a base inverse transform having M channels numbered 0 through $M-1$.

10. (Issued Patent) A method of coding, compressing, storing or transmitting, and decoding a block of $M \times M$ intensities from a digital image selected by an $M \times M$ window moving recursively over the image, comprising the steps of:

- a. Processing the intensities in an $M \times M$ block coder comprising the steps of:
 - i. processing the intensities through an initial stage;
 - ii. scaling the result of the preceding step in each channel;
- b. processing the result of the preceding step through a cascade comprising a plurality of dyadic rational lifting transforms, each of said plurality of dyadic rational lifting transforms comprising
 - i. a first bank of pairs of butterfly lifting steps with unitary coefficients between adjacent lines of said transform;
 - ii. a bank of delay lines in a first group of $M/2$ alternating lines;
 - iii. a second bank of butterfly lifting steps with unitary coefficients, and
 - iv. a bank of pairs of butterfly lifting steps with coefficients of $1/2$ between $M/2 - 1$ pairs of said $M/2$ alternating lines;
- c. transmitting or storing the output coefficients of said $M \times M$ block coder;
- d. receiving the output coefficients in a decoder; and

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- e. processing the output coefficients in the decoder, comprising the steps of
 - i. processing the output coefficients through a cascade comprising a plurality of dyadic rational lifting transforms, each of said plurality of dyadic rational lifting transforms comprising
 - a) a bank of pairs of butterfly lifting steps with coefficients of $1/2$ between said $M/2 - 1$ pairs of said $M/2$ alternating lines;
 - b) a first bank of pairs of butterfly lifting steps with unitary coefficients between adjacent lines of said transform;
 - c) a bank of delay lines in a second group of $M/2$ alternating lines;
 - d) a second bank of pairs of butterfly lifting steps with unitary coefficients between adjacent lines of said transform;
 - e) a de-scaling bank; and

processing the results of the preceding step in an inverse initial stage.

11. (Issued Patent – currently being amended) The apparatus of Claim 1 in which the ~~constants~~ coefficients are approximations chosen for rapid computing rather than exact ~~constants~~ coefficients.

12. (Preliminary Amendment – currently being amended) A method of processing blocks of samples of digital signals of integer length M comprising processing the digital samples of length

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M with an invertible linear transform of dimension M, said transform being representable as a cascade, using the steps, in arbitrary order, of:

- a) at least one +/-1 butterfly step,
- b) at least one lifting step with rational complex coefficients, and
- c) at least one scaling factor.

13. (Preliminary Amendment -- original) The method of Claim 12 additionally comprising the step of at least one time delay.

14. (Preliminary Amendment -- original) The method of claim 12, wherein the rational complex coefficients in the lifting steps are dyadic.

15. (Preliminary Amendment -- original) The method of claim 12, wherein

- a) said invertible transform is an approximation of a biorthogonal transform;
- b) said biorthogonal transformation comprises a representation as a cascade of at least one butterfly step, at least one orthogonal transform, and at least one scaling factor;
- c) said at least one orthogonal transform comprising a cascade of
 - ii) at least one +/-1 butterfly step,
 - iii) at least one planar rotation, and
 - iv) at least one scaling factor;
- d) said at least one planar rotation being represented by equivalent lifting steps and scale factors; and,

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e) said approximation being obtained by replacing floating point coefficients in the lifting steps with rational coefficients.

16. (Preliminary Amendment -- original) The method of claim 15, wherein the coefficients of the lifting steps are chosen to be dyadic rational.

17. (Preliminary Amendment -- original) The method of claim 12, wherein the invertible transform is a unitary transform.

18. (Preliminary Amendment -- original) The method of claim 12, wherein

a) said invertible transform is an approximation of a unitary transform;

b) said approximation of the unitary transform comprises a representation of the unitary transform as a cascade of at least one butterfly step, at least one orthogonal transform, and at least one scale factor;

c) said at least one orthogonal transform being represented as a cascade of

(1) at least one ± 1 butterfly steps,

(2) at least one planar rotation, and

(3) at least one scaling factor;

d) said at least one planar rotation being represented by equivalent lifting steps and scale factors; and,

e) said approximation being derived by using approximate rational values for the coefficients in the lifting steps.

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19. (Preliminary Amendment -- original) The method of claim 18, wherein the invertible transform is an approximation of a transform selected from the group of special unitary transforms: discrete cosine transform (DCT); discrete Fourier transform (DFT); discrete sine transform (DST).
20. (Preliminary Amendment -- original) The method of claim 18, wherein the coefficients of the lifting steps are dyadic rational.
21. (Preliminary Amendment -- original) The method of claim 18, wherein at least one of the following lifting steps is used, whose matrix representations take on the form:
- $$\begin{bmatrix} 1 & a \\ 0 & 1 \end{bmatrix}, \begin{bmatrix} 1 & 0 \\ b & 1 \end{bmatrix}, \text{ where } a, b \text{ are selected from the group:}$$
- +/- {8, 5, 4, 2, 1, 1/2, 1/4, 3/4, 5/4, 1/8, 3/8, 2/5, 5/8, 7/8, 1/16, 3/16, 5/16, 7/16, 9/16, 11/16, 13/16, 15/16, 25/16}.
22. (Preliminary Amendment -- original) The method of claim 21, wherein the invertible transform is an approximation of a transform selected from the group of special unitary transforms: discrete cosine transform (DCT); discrete Fourier transform (DFT); discrete sine transform (DST).
23. (Preliminary Amendment -- original) The method of claim 22, wherein the approximation of the 4-pt DCT is selected from the group of matrices:

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$$\left\{ \begin{bmatrix} 1 & 1 & 1 & 1 \\ 2 & 1 & -1 & -2 \\ 1 & -1 & -1 & 1 \\ 1 & -1 & 1 & -1 \end{bmatrix}, \begin{bmatrix} 1 & 1 & 1 & 1 \\ 2 & 1 & -1 & -2 \\ 1 & -1 & -1 & 1 \\ 1 & -2 & 2 & -1 \end{bmatrix}, \begin{bmatrix} 1 & 1 & 1 & 1 \\ 2 & 1 & -1 & -2 \\ 1 & -1 & -1 & 1 \\ 5 & -2 & 2 & -5 \end{bmatrix} \right\}$$

24. (Amended) The method of Claim 19 in which the invertible transform is an approximation of a transform selected from the group three point DCT, 4 point DCT, 8 point DCT, and 16 point DCT.

25. (Amended) The method of Claim 19 in which the invertible transform is an approximation of a transform selected from the group 512 point FFT, 1024 point FFT, 2048 point FFT, and 4096 point FFT.